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DEPARTMENT OF PSYCHOLOGY

The University of Michigan, Ann Arbor

The Effect of Complexity in Integrated Multidimensional Displays

MOSHE BENJAMIN &
ROBERT G. PACHELLA

Technical Report No. 66
December 1980

THE HUMAN PERFORMANCE CENTER

DEPARTMENT OF PSYCHOLOGY

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THE UNIVERSITY OF MICHIGAN

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THE EFFECT OF COMPLEXITY IN INTEGRATED MULTIDIMENSIONAL DISPLAYS

Moshe Benjamin and Robert G. Pachella[1]

HUMAN PERFORMANCE CENTER TECHNICAL REPORT NUMBER 66

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Abstract

The total number of irrelevant features was systematically varied in set complex multidimensional displays for which subjects were asked to make pairwise similarity judgments. The results showed that observers could not ignore distinctive irrelevant features even under strong instructions to do so, although they could ignore common irrelevant features. It is suggested that the salience of irrelevant information and the relations between relevant and irrelevant information, rather than the amount of irrelevant information per se, are crucial factors in determining the potential for perceptual interference.

The Effect of Complexity In Integrated Multidimensional Displays

The availability of computerized graphic devices has greatly improved the techniques of presenting complex quantitative information to human observers. With this modern technology, multivariate data can be presented in the form of complex geometric patterns and pictorial displays that can potentially code large amounts of information. One important use for displays such as these is to represent the status of a complex system, both continuously and in real time, by mapping each system variable into some dimension or aspect of a displayed pattern or picture. In many control and monitoring situations such displays can replace or at least supplement entire panels of dials and meters, which, in contrast, display each system variable separately.

With regard to human factors, at least two advantages are assumed to accrue as a result of the use of these multivariate graphic representations. First, integration of information can be achieved because of the spatial coherence of the displayed pattern or picture. With an integrated display, all of the information is available to the observer in a single glance. By contrast, information presented in separate displays forces the observer to attend to each system variable independently. Integration of information in this case can only be achieved by means of mental comparison or computation by the observer. Second, geometric representations and pictorial displays maximize the powerful pattern recognition abilities of the human percpetual system. Human pattern perception is primarily sensitive to relations among the component aspects of a display. Consequently, an observer viewing an integrated pattern representing a complex system can directly perceive underlying

correlations among the system variables. In both cases, an integrated display format allows the observer to work with a representation which is highly compatible with certain basic human abilities.

Integrated multidimensional displays also present some difficulties, however. The same pattern recognition abilities that yield advantages with regard to the integration of information can also cause perceptual interference among the display dimensions under certain circumstances. This interference can take several forms. One of these has been referred to as filtering decrement (Garner and Felfoldy, 1970). As noted above, when an observer views an integrated display, relational information can be extracted with greater efficiency than it can from separate displays. However, as a result of the increased salience of relational features the observer has greater difficulty attending to the component aspects of the display by themselves. That is, if an observer is called upon to filter relevant information from irrelevant information in the display, the more coherent the pattern, the more difficult is the task. Thus, integrated displays are best used in tasks that rely exclusively on relational information.

The second kind of interference is a function of the psychophysical compatibility of the display (Pachella, Somers and Hardzinski, 1981). Complex geometrical patterns have potentially an infinite number of physical descriptions, each of which could be used as the basis for assigning system variables to the display. Psychophysical compatibility refers to the extent to which each of these possible descriptions correspond to the most salient and perceivable attributes of the displayed pattern. When the physical description used for assigning system variables

has little correspondence to the perceived attributes of the display, that is, when there is low psychophysical compatibility, the physical variables will interfere with each other. Both of these factors, filtering decrement and psychophysical compatibility, have been shown to produce significant performance decrements with the use of integrated multidimensional displays (Pachella and Somers, 1979; Somers, 1978; Cheng, 1980).

The present experiment attempts to explore a third category of difficulty in the use of integrated multidimensional displays: the effect of the complexity of the irrelevant information in the display. Tversky (1977) has proposed that adding common irrelevant information to a set of displays makes the displays more similar and hence less discriminable. On the other hand, the addition of distinctive irrelevant information should make the displays more dissimilar. Since actual applications of integrated displays often entail a considerable degree of complexity, it is important to determine whether the effects anticipated by Tversky (1977) will systematically affect performance. In particular, will similarity produced by common irrelevant features reduce the discriminability of the relevant information? Likewise, will the presence of distinctive irrelevant information exaggerate the perceivable differences on relevant dimensions?

The display format used in the present experiment was developed by Chernoff (1973) and has had extensive application as a graphical technique to represent multivariate data (Wang, 1978). The display utilizes a computer drawn schematic face that incorporates nineteen different, continuously variable features. This particular format takes advantage

of the unique human ability to process and recognize faces (Yin, 1969). In its application, up to nineteen different quantitative variables can be mapped into this representation and an observer can identify any particular configuration of these variables with a particular resulting face. In the present experiment, subjects were asked to judge the similarity of pairs of these facial displays with regard to just two of these characteristics. Different numbers of irrelevant features were then added to the displays, either in common (the same value of the features were added to both faces being compared) or distinctively (different values were added to each face of the pair). The question examined was whether or not the judgments of the relevant features were systematically affected by the amount and nature of the irrelevant information.

Method

Stimulus materials. The schematic faces that were used were similar to those developed by Chernoff (1973). All stimuli were drawn by a Calcomp Plotter under instructions from an Amdahl 470V/6 computer and were photographed as slide transparancies. The relevant features for the subject to judge comprised the outline shape of the face. The facial outline was composed of the orthogonal combination of two levels of height to width ratio and two levels of dimple position (i.e., the point of intersection of the lower and upper circumference of the face). Thus there were four different outline shapes to be judged. These can be seen in Figure 1. The stimuli on the left are more narrow than those on the right and the upper stimuli have a higher dimple position than those on the bottom. The differences between the

faces were intentionally made small to ensure that the subjects would pay close attention to the stimuli. The characteristics of the eyes and nose were held constant for all stimuli.

Insert Figure 1 about here

There were three possible irrelevant dimensions: Eyebrows, mouth and pupils. Each of these dimensions, when present, could take on one of two values. The eyebrows could either slant upwards or downwards; the mouth could either curve upward or downward; and the pupils could be either in the center or in the left corner of the eye. These values were correlated with each other so that the upward slanting eyebrows always occurred in the context of an upward curving mouth and/or the pupils in the left corner of the eye. Alternatively, the downward slanting eyebrows always occurred with the downward slanting mouth and/or the pupils in the center of the eye. Thus, half of the stimuli had a "happy" expression on their face and half of the stimuli had a "sad" expression (see Figure 2). As a result of this manipulation, when a subject was judging two stimuli with a "happy" expression or two stimuli with a "sad" expression, the irrelevant information consisted of common features, and when the subject was judging one "sad" and one "happy" face, the irrelevant information consisted of distinctive features.

Insert Figure 2 about here

Each stimulus contained either zero, two or three irrelevant features. In the case of two irrelevant features one group of subjects

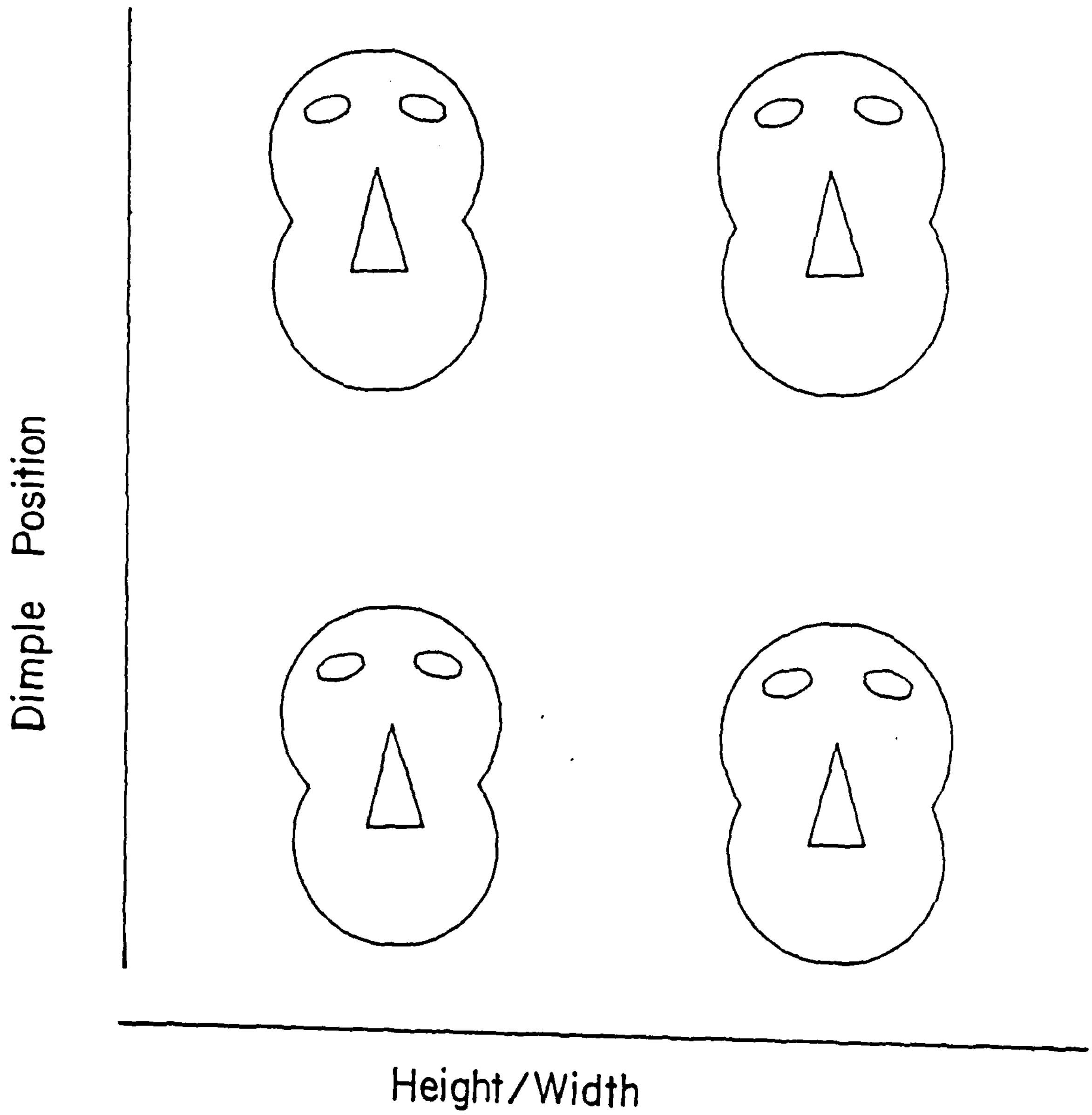

Figure 1. The 4 schematic faces created by combinations of height to width ratio and dimple position as the relevant features.

Figure 2. Facial expressions created by different combinations of mouth, eyebrows and pupils as the irrelevant features.

saw stimuli containing pupils and mouth, and another group of subjects saw stimuli containing pupils and eyebrows. The former group of subjects were designated "mouth second" since in going from zero to two to three irrelevant features the mouth was the second added irrelevant feature. The latter group of subjects were designated "mouth third" since for these subjects the mouth was the third added irrelevant feature. Examples of these stimuli, for one outline shape and the "happy" expression are shown in Figure 3.

Insert Figure 3 about here

Subjects. The subjects were 27 students obtained from the paid subject pool at the University of Michigan. Each subject participated in one experimental session lasting about 1 1/2 hours and was paid $3:50/ hour for his/her service.

Procedure. For each subject 24 stimuli were used, eight with zero irrelevant features, eight with two irrelevant features and eight with three irrelevant features. Twenty subjects were shown 276 stimulus pairs consisting of a random order of all possible pairs of the 24 faces. Ten of these subjects were in the "mouth second" condition. For these subjects the stimuli with two irrelevant features contained mouths and pupils. Eyebrows were added to create the stimuli with three irrelevant features. Ten subjects were in the "mouth third" condition in which the stimuli with two irrelevant features contained eyebrows and pupils. For these subjects, mouths were added to create the stimuli with three irrelevant features. Seven additional

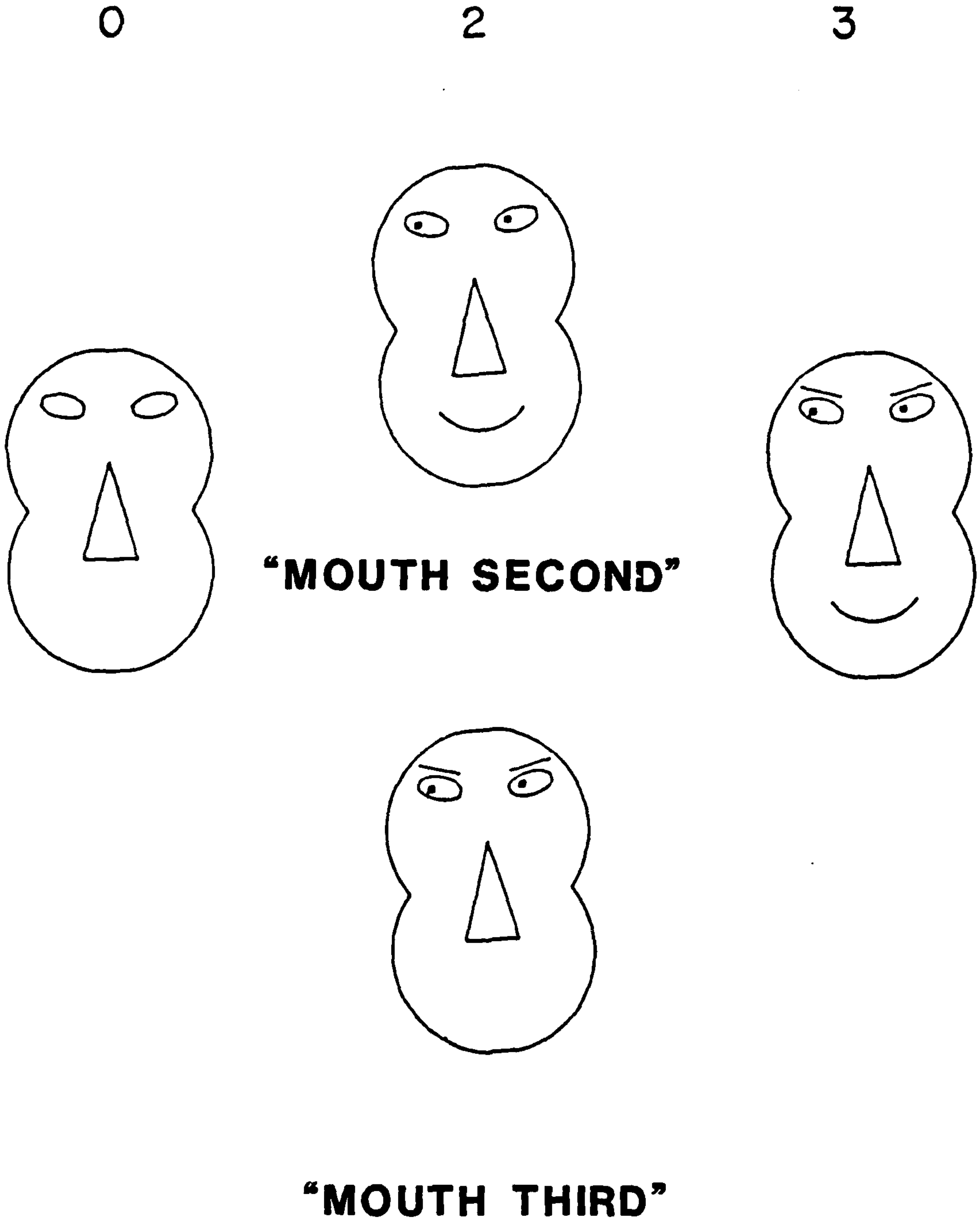

Figure 3. The 3 groups of stimuli determined by the number of irrelevant features.

subjects were shown only 132 pairs of stimuli consisting of all the pairs of the 24 faces which had only common features. That is, they never saw a pair of stimuli consisting of one "happy" expression and one "sad" expression. For all subjects in all groups, the first ten stimulus pairs were repeated at the end of the sequence.

The stimuli were projected onto a screen approximately ten feet from the subject. Each stimulus of a pair was projected to be a different size in order to prevent the subject from making a simple template match. The bigger stimulus of the pair was 7 degrees of visual angle and the smaller stimulus was 4 degrees of visual angle. The left-right position of the bigger stimulus was randomized across subjects.

Subjects were instructed to judge the similiarity of each pair of stimuli with regard to the shape of the outline of the face. They were instructed to ignore all other features of the face. Judgments were made on a ten point rating scale where 1 was very similar and 10 was very dissimilar. Subjects were encouraged to use the entire range of the scale and they were allowed as much time as they needed to make a judgment.

Results and Discussion.

The similarity ratings of the first and last ten trials for each subject were averaged together to get ratings that were consistent with the criteria used by the subject throughout the experimental session. Each subject's ratings were then subjected to a multidimensional scaling analysis utilizing a scaling program developed by Noma and Johnson (1977). This analysis yielded measures of dissimilarity

between all pairs of stimuli for each subject. Thus, the dependent variable can be considered to be a normalized discriminability measure.

The data from five subjects, 3 from the mouth second condition and 2 from the mouth third condition were excluded from further analysis because these subjects incorrectly based their judgments completely on the irrelevant features rather than the outline shape. Data from all other subjects within each group were then averaged together and submitted to statistical analysis.

The effect of common features was assessed in two different ways. As noted above, one group of subjects saw pairs of stimuli that contained only common irrelevant features. The other two groups of subjects (i.e. the mouth second and mouth third conditions) saw pairs of stimuli that contained both common and distinctive features. For these subjects measures of dissimilarity for just the pairs that contained common features were extracted, averaged together and compared to the judgments of the subjects who saw only pairs with common features. In this way the effect of the context of the experimental conditions could be assessed. No statistical difference for this comparison was found [$F(1,20) = 1.23$, n.s.]. Consequently the data from all three groups were averaged together.

Figure 4 presents the effects of adding different amounts of irrelevant common information to the discriminability of the relevant features. Analysis of variance showed no effect of the number of irrelevant features, [$F(2,63) = 1.28$, n.s.]. Thus, common irrelevant information does not appear to make the relevant information less discriminable.

Insert Figure 4 about here

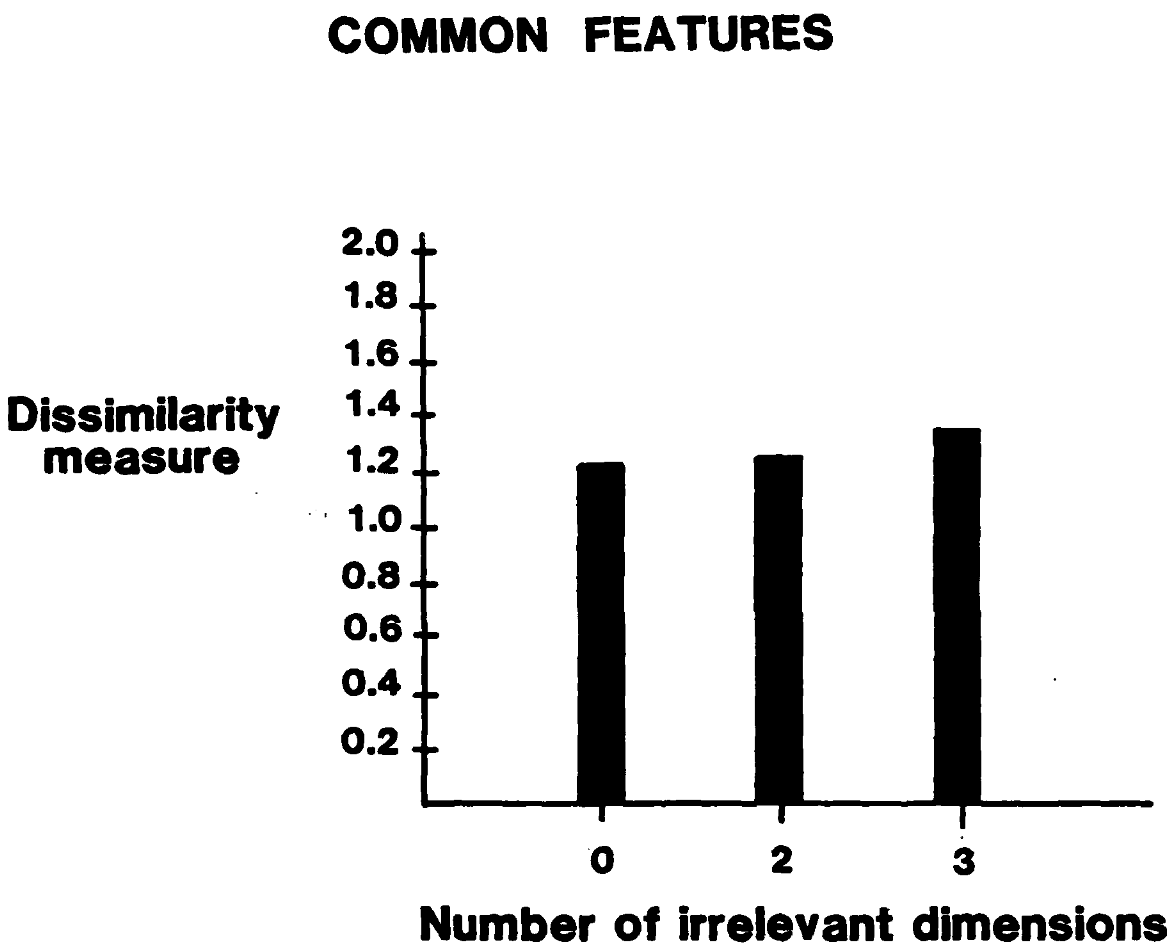

Figure 4. The effect of adding different amounts of irrelevant common information on the discriminability of the relevant features.

The effect of adding distinctive irrelevant information on the dissimilarity of the relevant features is somewhat more complex, however. Figure 5 presents the average dissimilarity of the outline shape of the faces averaged over all pairs of stimuli that contained distinctive irrelevant features for all subjects in both the mouth second and mouth third conditions. Adding two irrelevant distinctive features to the stimulus appears to increase the perceived dissimilarity of the outline shape and adding a third irrelevant distinctive feature increases the dissimilarity even more. This trend was significant by analysis of variance [$F(2,42) = 10.20$; $p < .001$]. Thus, the effect expected on the basis of the Tversky (1977) model is confirmed by the present data. It should be noted in this regard however, that the effect predicted by Tversky was for the overall dissimilarity of the stimulus. The present effect extends Tversky's notion by demonstrating a change in the perception of one feature as a result of the objective dissimilarity of a different irrelevant feature.

Insert Figure 5 about here

Tversky's (1977) model predicts monotonic effects of the impact of increasing amounts of information in a stimulus display, with common features decreasing the dissimilarity of the stimuli and distinctive features increasing the dissimilarity. The present experiment seems to have confirmed the second of these expectations. However, the irrelevant features in the present experiment were selected to have differential salience with regard to the overall appearance of the schematic face. The mouth feature was felt to have greater importance

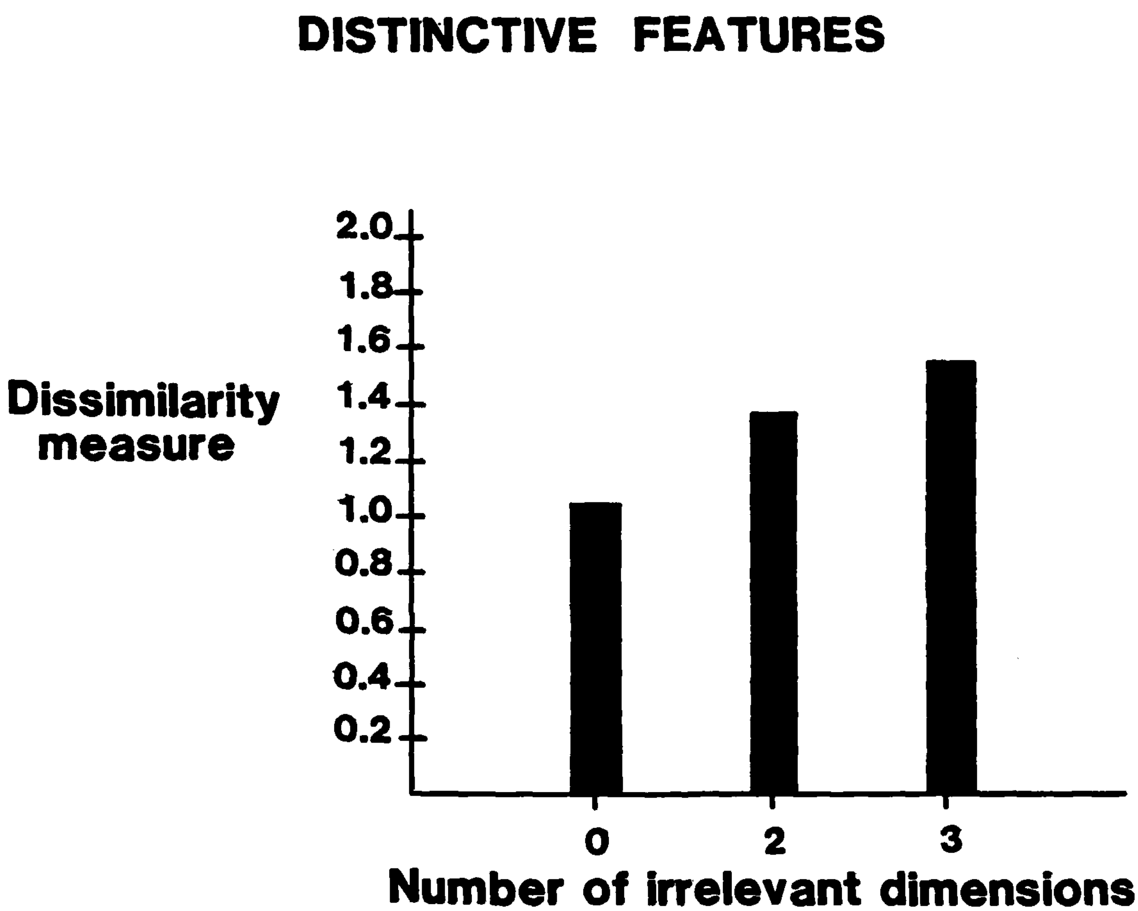

Figure 5. The effect of adding different amounts of irrelevant distinctive information on the discriminability of the relevant features.

to the facial character of the stimulus than was the addition of the eyebrow feature (see Figure 2). Thus, the experiment was designed to assess the independent contributions of these two features as a further test of the applicability of Tversky's model to the present situation.

Figure 6 presents the data for just those subjects for whom the mouth was the second added distinctive irrelevant feature of the display, the mouth second condition. Figure 7 presents the data for the condition in which the mouth appeared only in stimuli that had three irrelevant features, the mouth third condition. When the mouth was added as the second irrelevant feature there was a significant increase in going from zero to two irrelevant features [$F(1,12) = 20.10$; $p < .001$] but no change from two to three irrelevant features. By contrast, when the mouth was added as the third feature, there was no change from zero to two irrelevant features, but a significant change from two to three features [$F(1,14) = 11.5$; $p < .001$]. Thus, all of the effect of irrelevant information was due to the appearance of the mouth as a distinctive feature. The present data indicate therefore, that it is not the amount of distinctive irrelevant information per se that affects the similarity of the stimuli, rather it appears to be the salience of the feature to the overall appearance of the stimulus.

Insert Figures 6 and 7 about here

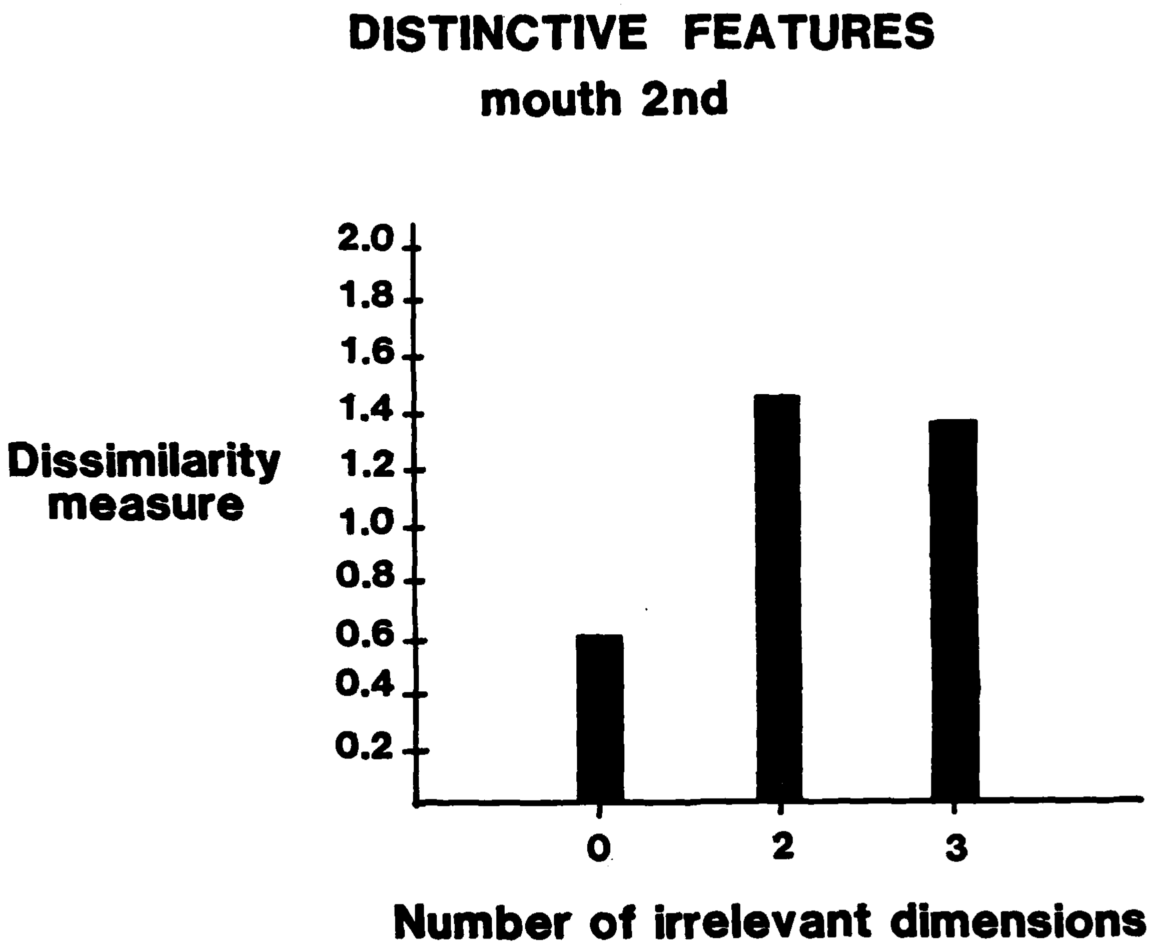

Figure 6. The specific effect of mouth when added as a second irrelevant distinctive feature.

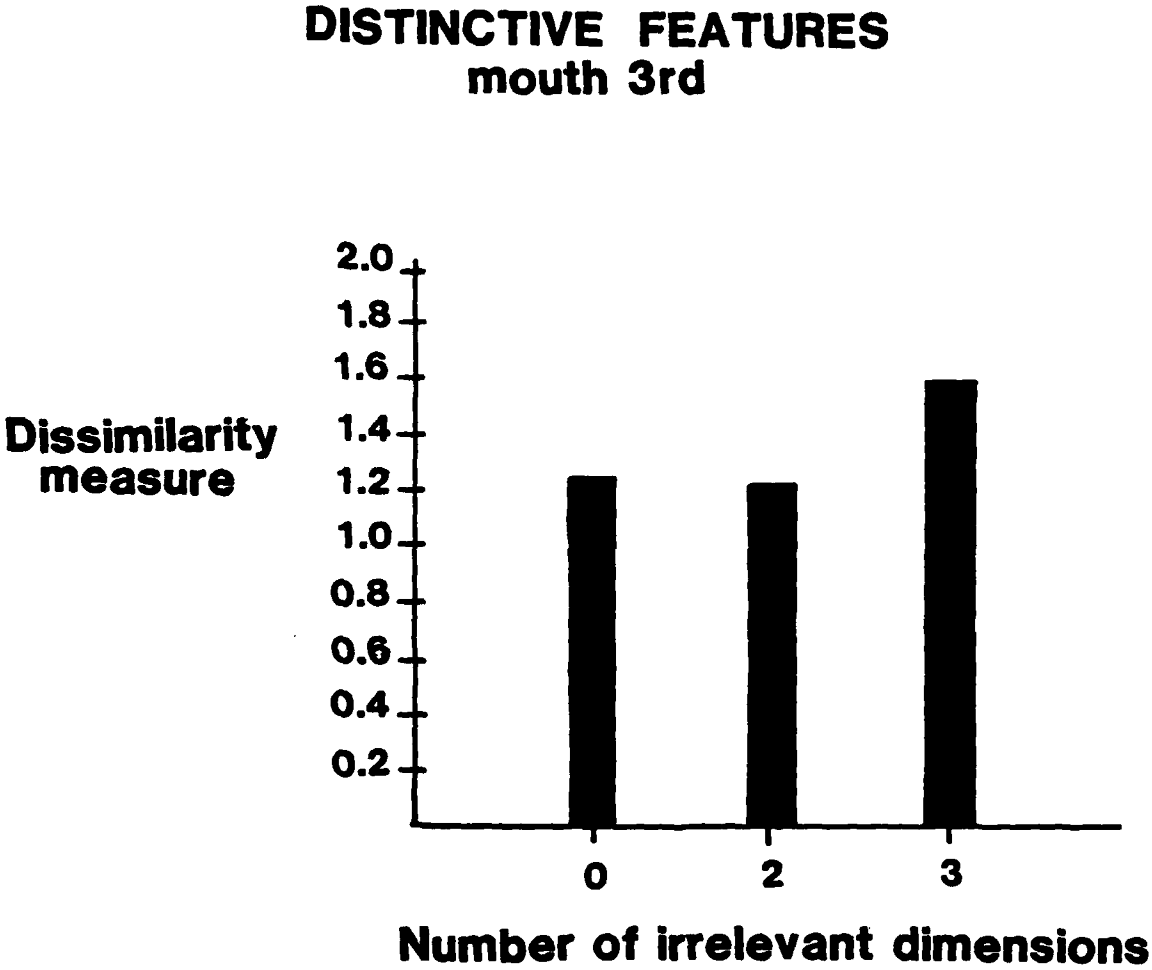

Figure 7. The specific effect of mouth when added as a third irrelevant distinctive feature.

In summary, several aspects of the present results should be emphasized. First, the presence of irrelevant information systematically affects the appearance of relevant information in integrated displays, even when subjects are under strong instructions to ignore this information. The effect found here goes beyond mere distraction caused by the presence of irrelevant information since common irrelevant features have no effect. Thus, the present effect does not simply represent failures of the subject to selectively attend to relevant information. Rather, the irrelevant information interacts with the relevant information to change its appearance, and this is the cause of the failure of attention observed here.

Second, because the effects found in this study were limited to the presence of distinctive information, the nature of the mechanisms underlying selective attention becomes more apparent. Subjects can clearly ignore irrelevant information. They do so when they are confronted with pairs of stimuli that contain common features. Even the presence of the salient feature of the mouth does not change the subject's judgments from the condition with zero irrelevant features as long as the irrelevant information is common to both stimuli being judged. The present data indicate that distinctiveness <u>attracts</u> attention. Finally, it is the salience of the feature for the overall appearance of the display that is effective. Neither the simple presence of irrelevant information nor its distinctiveness alone affects performance. A salient distinctive feature attracts attention and cannot be ignored. When this happens, the irrelevant information can modify the appearance of relevant information.

Integrated multidimensional displays have both advantages and

disadvantages. As noted earlier, they can enhance performance when their use is compatible with basic human abilities. However, there are important circumstances where performance decrements can result from their use. Pachella, Somers, and Hardzinski (1981) have detailed a theory of psychophysical compatibility that accounts for a number of these circumstances and describes how the mapping of physical display variables into perceived attributes determines the apparent integrality or perceptual cohesiveness of the display. The present study extends this previous work by demonstrating that irrelevant information can also interfere with the perceptability of display dimensions. The effect is mediated by the salience of the irrelevant information and not simply its presence or amount. In the terminology of Pachella, Somers and Hardzinski (1981) the potential for irrelevant information to interfere with relevant information depends on whether the physical attributes in question are integral, whether they combine with or modify salient features of the display. Regardless of the theoretical particulars, however, the present work, like the earlier studies, demonstrates important limitations to the use of integrated multidimensional displays.

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Footnotes

1. Request for reprints should be sent to Robert G. Pachella, Department of Psychology, University of Michigan, 330 Packard Road, Ann Arbor, Michigan, 48104, U.S.A.

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